THE EASTERN IDAHO/NORTHWEST WYOMING (TETONS) AND UTAH PROGNOSIS VARIANTS:

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Introduction

Prognosis (Stage, 1973) is an individual tree, distant independent growth and yield model which was developed for use in the Inland Empire area of Idaho and Montana. New "variants" of Prognosis result when Stage's Inland Empire model is calibrated for different geographic areas. Geographic variants of Prognosis have been developed for many areas in the western United States.

In 1981, the Intermountain Region requested Ralph Johnson, then a multi-Regional specialist stationed in Missoula, Montana, to develop a Prognosis variant for the Bridger-Teton, Caribou, and Targhee National Forests. On completion of this project in 1983, the Region asked for a similar project for the National Forests in Utah. This was a cooperative venture with Cooperative Forestry, WO Timber Management in Fort Collins, Pest Management, and Intermountain Station and resulted in the Utah variant of Prognosis. Figure 1 shows the general geographic area covered by these two variants.

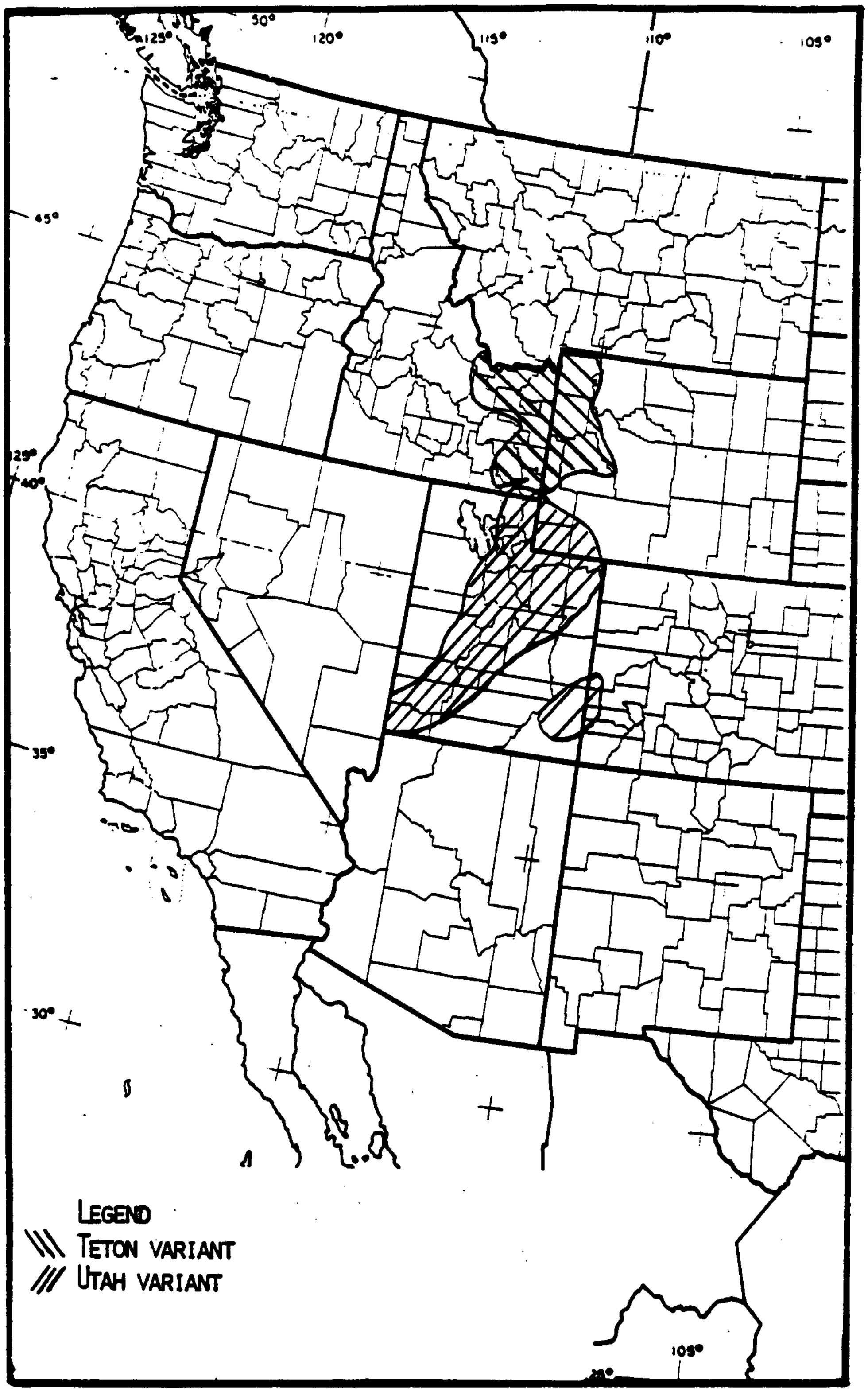

Figure 1. Geographic Area covered by the Teton and Utah Prognosis variants.

The models apply to a variety of species, forest types, and stand structures. Species include white bark/limber pine, Douglas-fir, Engelmann spruce, subalpine fir, ponderosa pine, and aspen. Prognosis is a versatile model and accomodates stand structures ranging from even-aged to uneven-aged, for a wide variety of forest types.

THE DATA BASE

Data sources, Assembly, and Editing

Data used to develop the models came from National Forest inventories and the Uinta Flats thinning study.

These data were converted to a common format and were edited for errors. Site index was available for all sample locations, however, the site index reference might have been from: Meyer (1938); Alexander, Tackle, and Dahms (1967); Alexander (1967); or Edminister et al (1985). The curve reference was retained as a variable in the data set.

Trees with measured DBH, diameter increment, and crown ratio were extracted from the data set using a computer program on the FCCC Univac computer. Density statistics for the start of the growth sample period were derived using a product of Basal Area Growth Ratio (BAGR). A unique BAGR was calculated for each species for each plot or cluster of plots. The BAGR was, of course, based only on trees having increment core measurements. Each tree was then grown back 10 years and the stand statistics calculated at that time. These statistics were back dated basal area and backdated crown competition factor (ccf). A tree's percentile in the basal area distribution was assumed to be equal at the start and end of the projected period.

Trees recorded as mortality were included in the backdated density after correction for the length of the mortality interval.

The end result was a computer file for each species, containing plot characteristics such as site index, slope, aspect, elevation, ccf, trees/acre, backdated basal area, backdated ccf, and stand age.

Data Distribution

Table 1 and Table 2 give the distribution of samples by species.

Table 1.

Utah Prognosis
No. of Growth Trees by site index group and species.

Species	<30	30-39	40-49	50-59	60+	Total
DF	202	541	323	103	42	1211
WF	283	45	49	24	12	413
LP	865	1023	372	10	1	2271
ES	586	544	272	95	32	1529
SAF	203	432	397	126	84	1242
PP	289	241	41	24	5	600

Table 2.

Teton Prognosis
No. of Growth Trees by species

Species	No. of Trees
WB	72
DF	2597
LP	2638
ES	971
AF	2288

Data Codes and Conversions

The following codes are used to enter stand and tree level data into the Teton and Utah Prognosis variants.

Prognosis5TT (Teton) Information

Prognosis Species Subscript	Prognosis Alpha Code	Common Name	Bark Ratios
1	WB	Whitebark Pine	.969
2	LM	Limber Pine	.969
3	DF	Douglas-fir	.867
4	DM1	Dummy 1	.915
5	DM2	Dummy 2	.934
6	AS	Aspen	.950
7	LP	Lodgepole Pine	.969
8	ES	Engelmann Spruce	.956
9	AF	Subalpine Fir	.937
10	DM3	Dummy 3	.890
11		Other (other grown as Whitebark)	.969

Prognosis Forest Subscript	Region 4 Code	Forest Name
1	3	Bridger
2	5	Caribou
3	15	Targee
4	16	Teton

Prognosis5UT (Utah) Information

Prognosis Subscript	Prognosis Alpha Code	Common Name	Bark Ratios
1	WB	Whitebark Pine	.969
2	LM	Limber Pine	.969
3	DF	Douglas-Fir	.867
4	WF	White Fir	.915
5	DM	Dummy	.934
6	AS	Aspen	.950
7	LP	Lodgepole Pine	.969
8	ES	Englemann Spruce	.956
9	AF	Subalpine Fir	.937
10	PP	Ponderosa Pine	.890
11		Other (grown as Whitebark)	.969

Prognosis Forest Subscript	Region 4 Code	Forest Name
1	1	Ashley
2	7	Dixie
3	8	Fishlake
4	10	Manti-Lasal
5	18	Uinta
6	19	Wasatch

Site index is coded as follows in both variants.

Site Species Code	Site Species	References
1	WB/LM	Use Lodgepole
2	WB/LM	Use Lodgepole
3	DF	Use Brickell's cuft conversion
6	AS	Edminister, Mowrer and Shepperd, Res. Note RM 453 (Utah only)
7	LP	Alexander, Tackle, and Dahms, Res. Paper RM 29
8	ES	Alexander, Res. Paper RM 32
9	AF	Use ES
10	PP	Meyer, Tech. Bull. 630

However, all site indexes must be entered as a 50 year base index. That is, if the curve you use is a 100 year base curve, you must convert the site index to a 50 year base before entering the index in the model.

Habitat code is not used in either Utah or Teton and elevation is recorded in hundreds of feet.

Slope is coded as follows in both variants:

Code	Slope Percent
0	0-5
1	6-15
2	16-25
3	26-35
4	36-45
5	46-55
6	56-65
7	66-75
8	76-85
9	86+

Aspect is coded as follows in both variants:

Code	Aspect
0	level
1	N
2	NE
3	E
4	SE
5	S
6	SW
7	W
8	NW
9	No meaningful aspect

Crown ratio codes are as follows in both variants:

Code	Percent CR
1	1-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81-100

Data Limitations

Tables 1 and 2 show white bark pine and white fir as having limited samples. Users should use caution when making simulations of these species.

The Teton and Utah variants of Prognosis are patterned after Version 5 of the Stand Prognosis Model (Wykoff et. al., 1982 and Wykoff, 1986). Major improvements in Version 5 models include the Establishment Submodel to establish natural or artificial regeneration (Ferguson and Crookston, 1984), and the Event Monitor (Crookston, 1985) which schedules management activities if certain user specified conditions are met. Both of these features are part of the Utah and Teton variants. Functional relationships embedded in Version 5 were modified for Utah and Teton to make the model more responsive to local geographic conditions. These functional relationships can be separated into three submodels; establishment, small tree, and large tree.

Establishment Submodel

The establishment submodel is linked to 5TT and 5UT, however, data were not currently available to calibrate the establishment submodel for the area covered. As a result, natural regeneration is automatically suppressed and the only viable method of establishing new trees in the simulation is by "planting". The minimum set of stand management keywords to get a projection from planting trees on bare ground is:

```
ESTAB       1985.
PLANT       1985.     10.      460.
END
NOTREES
```

Timing of establishment is discussed in Ferguson and Crookston.

In the establishment submodel, height is estimated first, then diameter, followed by crown ratio. Since data were not available to calibrate all of this submodel, equations for height and diameter growth from the small tree submodel are also used here for growth of regenerated trees. Basically, height growth is calculated for the length of time between planting and the end of the projection cycle using equation {1} in the Teton variant and equation {3} in the Utah variant. Diameters are estimated using equations which contain species and crown ratio dependent coefficients. For purposes of the establishment submodel, a constant crown ratio of 70 percent is assumed. These equations and coefficients will be discussed in detail in the next section.

Small Tree Submodel

Small tree HTG is calculated using a technique dependent on the variant.

Teton

Height growth is calculated as a function of site, crown, BAL, and age. The function is given as equation 1.

$$\mathrm{Ln}\,(HT) = \frac{a - b\,\mathrm{Ln}(site) - c\,(cr) - d(BAL \cdot AGE)}{e} \qquad \{1\}$$

All trees have a height (H_o) and crown ratio (either measured or dubbed) in Prognosis. For all species except aspen, equation 1 is first evaluated for an effective age given a height, site, BAL, and CR. Age is incremented by 10 and equation 1 is solved for a new height (H_{10}). Height growth is calculated as $H_{10}-H_o$. Table 3 gives the coefficients used in equation 1. Aspen height growth is computed as discussed for the Utah variant.

Table 3. Coefficients used in the small tree growth model of the Teton Prognosis.

Species	Coefficients a	b	c	d	e
WB/LM	1.8251	-0.0295	-0.1894	0.0355	0.7882
DF	1.8144	0.0110	0.10873	0.03731	0.48907
LP	1.7231	-0.0183	0.00901	0.0538	0.5862
ES	1.1797	0.00744	0.3501	0.03023	0.64298
AF	2.0061	-0.03076	-0.06976	0.00775	0.72685

Diameter growth is calculated using a technique similar to the one used for height growth, using equation 2. Coefficients for equation 2 are given in Table 3a.

$$\mathrm{Ln}\ (D) = \frac{\mathrm{Ln}(H - 4.5) - a - b(BAL)}{c} \qquad \{2\}$$

Equation 2 is solved first using H_o and second using H_{10}. Diameter growth is $D_{10}-D_o$.

Table 3a. Coefficients for the small tree diameter growth model for the Teton prognosis.

Species	Coefficients a	b	c
WB/LM	1.1775	0.01318	0.8645
DF	1.5941	0.004271	1.05189
LP	1.3559	0.02115	1.1309
ES	1.4464	-0.0001121	0.9487
AF	1.3773	-0.00003196	0.9248

Utah

In Utah, small tree height growth is calculated as a function of site and Basal area using equation 3. The coefficients are presented in Table 4. This relationship was developed after consultation with R4 silviculturists.

$$HTG = a_{ij} + b_{ij}\ (BA) + C_{ij}\ (BA)^2 \qquad \{3\}$$

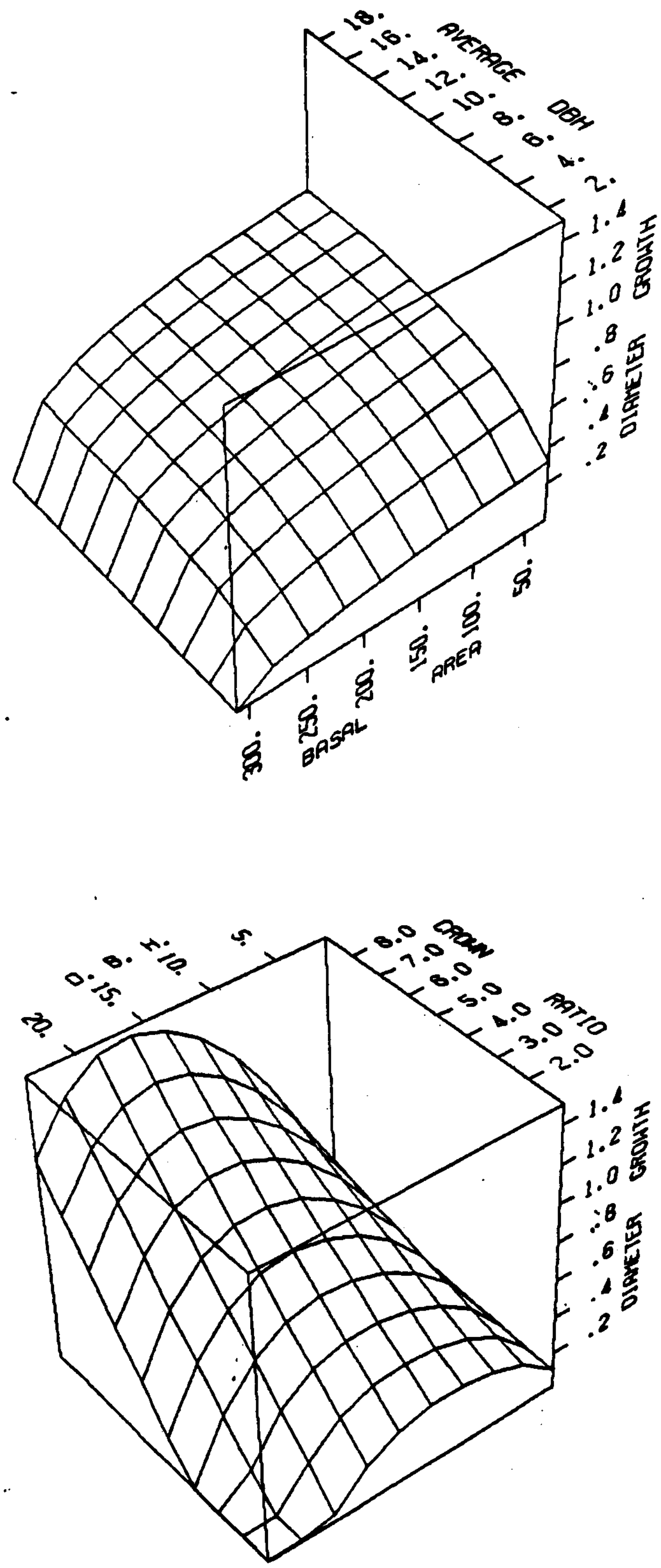

Figure 4. Aspen diameter growth response surface.

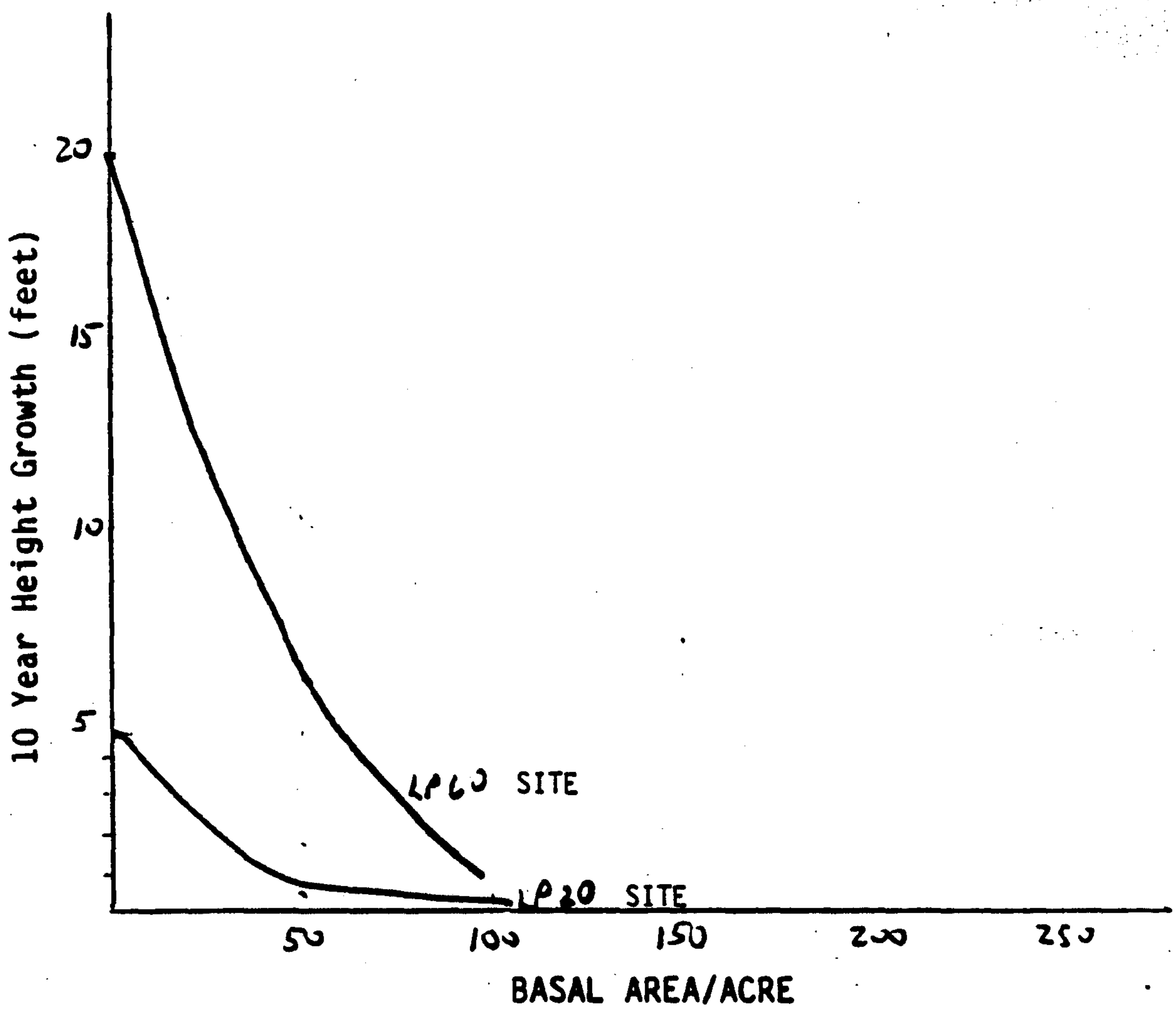

Figure 2. Height growth for small lodgepole in the Utah Prognosis variant.

In the Utah variant, small tree diameter growth for all species exce calculated using a Weibull function {4}, specific to BAL and the ran deviation from the height growth step. Coefficients are given in Ta

scale = a + b (BAL)
shape = c + d (BAL)

$$DG = \frac{\left(scale \cdot \left(Ln\left\{\frac{1}{1-P}\right\}\right)^{\frac{1}{shape}}\right)}{10}$$

Where p = random # [0,1]
BAL = [25,225]

For small Utah Aspen, diameter growth is calculated using a height-c function {5}.

$$D_o = \frac{a}{Ln\,(H_o-4.5)-b} \quad -1.0$$

$$D_{10} = \frac{a}{Ln(H_{10}-4.5)-b} \quad -1$$

First, a diameter, D_o, is computed using H_o. Next a diameter, D_{10}, computed using H_{10}, where $H_{10} = H_o + HTG$.

Diameter growth is then computed as $DG = D_{10}-D_o$

Table 5. Coefficients for the scale and shape parameters for the sma diameter growth Weibull function Utah Prognosis.

Species	a	b	c	d
WB/LM	10.8455	-0.03258	1.72400	0.00516
DF	10.55917	-0.02630	2.87833	-0.01060
LP	10.84550	-0.03258	1.72400	0.00516
ES	9.03110	-0.02094	1.18153	0.00504
AF	9.86650	-0.01626	1.97000	0.00008
PP	16.03167	-0.06500	2.45750	-0.00090

Weighting small tree and large tree HTG.

In the Utah and Teton variants there is no weighting function for tı through the transition the small tree model to the large tree model. result in some irregularities in individual tree growth.

Small tree crowns.

For both the Teton and Utah variants, small tree crowns do not change until the tree exceeds 1" dbh. If the tree has no crown ratio, one is estimated using function {6}.

$$\{6\} \quad CR = 1.0/(1.0 + \exp(b_o + b_1 \cdot DBH + b_2 \cdot HT + b_3 \cdot BA + b_4 \cdot BAL + b_5 \cdot \text{point CCF} + b_6 \cdot (hT_{40}/HT) + b_7 \cdot (\text{site index}) + b_8 \cdot HT_{40} + b_9 \cdot (BA \cdot \text{Point CCF}) + b_{10} \cdot MAI + b_{11} \cdot DBH^2)$$

Table 6. Coefficients for the small tree crown estimation model for the Teton and Utah Prognosis variants.

	Species WB	LM	DF	WF	AS	LP	ES	AF	PP
b_0	-1.6695	-1.6695	-.4267	-.4267	-.4267	-1.6695	-.4267	-.4267	-1.6695
b_1	-.2098	-.2098	-.0931	-.0931	-.0931	-.2098	-.0931	-.0931	-.2098
b_2	.0000	.0000	.0224	.0224	.0224	.0000	.0224	.0224	.0000
b_3	.0034	.0034	.0026	.0026	.0026	.0034	.0024	.0024	.0034
b_4	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
b_5	.0110	.0110	.0000	.0000	.0000	.0110	.0000	.0000	.0110
b_6	.0000	.0000	-.0455	-.0455	-.0455	.0000	-.0455	-.0455	.0000
b_7	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
b_8	.0177	.0177	.000	.0000	.0000	.0177	.0000	.0000	.0177
b_9	-.00005	.00005	.00002	.00002	.00002	-.00005	.00002	.00002	-.00005
b_{10}	.0141	.0141	-.0131	-.0131	-.0131	.0141	-.0131	-.0131	.0141
b_{11}	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

Large Tree Submodel

Diameter Growth-(except Aspen)

The estimation sequence in the large tree growth submodel begins with diameter change followed by height change, and finally crown ratio change is predicted. Large tree diameter growth, equation {7}, is calculated by a log linear regression. Actually, the equation predicts log of change in diameter growth squared. Coefficients for equation {7} are shown in Table 10 for the Utah variant and Table 15 for the Teton variant.

$$\begin{aligned} Ln(dds) = {} & constant + b_1 \, Ln(DBH) + b_2 \, (BAL) \\ & + b_3 \, (CR) + b_4 \, (CR)^2 + b_5 \, (DBH)^2 \\ & + b_6 \, (PCCF) + b_7 \, (CCF)/100 \end{aligned} \quad \{7\}$$

Where:

$$\begin{aligned} constant = {} & c_{i,j}(SITE) + \\ & + \text{Location intercept} + C_2 \cdot SIN\,(Aspect) \cdot slope \\ & C_3 \cdot COS\,(Aspect) \cdot Slope + C_4 \cdot (Slope) \\ & + C_5 \cdot (Slope)^2 \end{aligned}$$

i = species
j = site reference

Slope = Slope as a ratio (.1 for 10%)
BAL = Basal Area in larger trees (A measure of suppression)
CR = Crown ratio as a percent (0-99)
Site = actual index value
CCF = Crown competition factor.
PCCF = Crown competition factor for the point.

Not all terms in {7} are used for all species. Coefficients are 0 for these unused terms. Location, ccf, site, and DBH^2 use a value for a class. To find which coefficient value to use, first look in Tables 7-9 or 11-14. For example, if you are using a Caribou stand and the species in question is Lodgepole pine, read across Table 12 to LP then down to Caribou and find a 1. On Table 15 for LP the coefficient for class 1 is .494205.

For a given tree there is only one location intercept, site coefficient, dbh^2 coefficient, and ccf coefficient.

Table 7. Utah Prognosis classification of DBH^2 coefficients by species.

	Species					
Forest	WB/LM	DF	LP	ES	AF	PP
Ashley	1	1	1	1	1	1
Dixie	1	1	1	1	1	2
Fishlake	1	1	1	1	1	1
Manti-LaSal	1	1	1	1	1	1
Uinta	1	1	1	1	1	1
Wasach	1	1	1	1	1	1

Table 8. Utah Prognosis classification of Geographic Location intercepts by species.

	Species					
Forest	WB/LM	DF	LP	ES	AF	PP
Ashley	1	1	1	1	1	1
Dixie	1	2	1	1	2	2
Fishlake	1	2	1	1	1	2
Manti-LaSal	1	2	1	2	1	3
Uinta	1	3	2	3	1	3
Wasach	1	4	3	4	3	3

Table 9. Utah Prognosis classification of site index references by species.

	Site Species						
Forest	LP	DF	AF	ES	ASP	WF	PP
WB/LM	1	1	1	1	1	1	1
DF	1	2	1	3	1	1	1
LP	1	1	1	2	2	2	2
ES	1	2	2	2	2	2	2
AF	1	1	2	2	3	2	2
PP	1	1	1	1	1	2	3

Table 10. For the Utah variant. Coefficients for the diameter increment model by species.

	Species					
	WB/LM	DF	LP	ES	AF	PP
Site (Species Class)						
1	.199592	0.010968	0.21764	0.15133	0.004468	0.019282
2		0.06827	0.27956	0.21085	0.008147	0.049804
3		0.199457			-0.015283	0.02943
Location Class Intercepts						
1	1.911884	0.192136	-0.256987	0.011943	-0.467188	-0.13235
2		-0.064516	-0.425846	0.265071	-0.638653	-0.460129
3		0.477698	0.530457	-0.94861	0.116430	-0.302309
4		0.589169		0.796948		
CCF	-0.199592	0.0	-0.043414	-0.043414	0.0	0.0
Sin (Aspect) *SL	-0.017520	0.022753	0.128610	-0.122483	-0.192975	-0.287654
Cos (ASP) *SL	-0.609774	0.015235	-0.168522	-0.198194	-0.232267	-0.411292
Slope	-2.057060	-0.532905	0.120589	0.240433	0.383578	0.016965
$Slope^2$	2.11326	-0.086518	-0.266226	0.0	0.333955	2.282665
Lm(DBH)	0.213947	0.479631	0.587503	0.587579	0.833096	0.733305
CR	1.523464	3.182592	2.148640	0.331129	1.422919	1.315804
CR^2	0.0	-1.310144	-0.598897	0.816301	0.225676	0.238917
BAL	-0.358634	-0.707380	-0.192073	-0.399357	-0.182808	-0.320124
PCCF	0.0	-0.001613	-0.000467	0.0	-0.000200	-0.002576
DBH^2 Class						
1	0.0006538	0.0	0.0	0.0	-0.0001672	-0.0005345
2						-0.0006363

Table 11. Classification of Species Base Dependent SI Coefficients Teton Prognosis

		Class No. Species					
Species Base [1/]		**WB/LM**	**DF**	**AS**	**LP**	**SP**	**AF**
Lodgepole	1	1	1	1	1	1	1
Douglas fir	2	1	1	1	1	1	1
Subalpine fir	3	1	1	1	1	1	1
Spruce	4	1	1	1	2	2	2
Aspen	5	1	1	1	2	2	2

[1/] This is the species used to determine site index. It is used to indicate which site index publication was used.

Table 12. Classification of Location Effects by Species Among National Forests for the Diameter Increment Model. Teton Prognosis.

	Location Classes					
	WB/LM	DF	AS	LP	ES	AF
Bridger	1	1	1	1	1	1
Caribou	1	1	1	1	1	1
Targhee	2	2	2	2	2	2
Teton	3	3	1	2	3	3

Table 13. Classification of CCF Coefficients by Species by Site Class for the Diameter Increment Model. Teton Prognosis.

	Species Code					
SI Index Class	WB/LM	DL	AS	LP	ES	AF
20	1	1	1	1	1	1
30	1	2	1	1	1	1
40	1	2	1	1	2	1
50	1	2	1	1	3	2
60	1	2	1	1	3	2

Table 14. Classification of Diameter Squared Effects by Species among National Forests for the Diameter Increment Model. Teton Prognosis.

	Location Classes Species Code					
	WB/LM	DF	AS	LP	ES	AF
Bridger	1	1	1	1	1	1
Caribou	1	1	1	1	1	1
Targhee	1	1	1	2	1	1
Teton	1	1	1	3	1	2

Table 15. Coefficients for the Diameter Increment Model by Species. Teton Prognosis.

Variables	Class	WB/LM	DF	AS	LP	SP	AF
Site-Species	1	.001766	.011597	.472247	.009756	.011389	.003955
	2				.014334	.019985	.006310
Location Class	1	1.911884	1.084994	1.543622	.494205	1.543251	.921658
	2	1.568742	.796640	1.643733	.502908	.943003	.807282
	3	2.001195	1.042871			.792165	.914279
	4						
CCF/100 by Site Class	1	-.199592	-.641932	.472247	-.206752	-.045495	-.186614
	2		-.141370			-.204852	-.023236
	3					-.311383	
COS(ASP).SL		-.609774	-.268610	.042546	-.075306	-.698103	-.178369
SIN(ASP).SL		-.017520	-.076614	.332422	-.036871	.102053	.052805
SL		-2.057060	-.711260	-.243008	-.129291	1.335928	.784185
SL^2		2.113263	0.0	0.0	0.0	-1.481349	-1.504007
Lm(DBH)		.213947	.533965	-.368391	.563751	.378802	.648535
CR		1.523464	1.931900	4.034753	2.164346	1.098353	.137638
CR^2		0.0	-.894368	5.617552	-.625799	0.0	1.066542
(BAL/100)		-.358634	-.574858	-.704392	-.469671	-.49005	-.312129
DBH^2 classes	1	.0006538	-.0001997	.0058612	0.0	-.0001056	-.0002152
	2				-0.0009803		-.0002567
	3				-0.0016416		

Aspen Diameter Growth

Because of the clumping and cloning nature of Aspen, using the standard methods derived by Wykoff gave a misrepresentation of the density effect. Good healthy clones tended to have better growth, resulting in a positive term for the ccf coefficient. This would mean more ccf would result in better growth. Pretty soon one would have wall to wall trees. For this reason, these variants use the technique used for aspen in the Lake States STEMS model. It works as follows:

1) A potential diameter growth is calculated

$$POTDG = (.4755 - 3.8336E\text{-}6 \cdot (DBH)^{4.1488}) + (0.04510 \cdot (CR) \cdot ((R) \cdot (DBH)^{0.67266}) \qquad \{8\}$$

2) A relative density function is calculated {9}

$$FOFR = 1.07528 \cdot (1.0 - \exp^{(-1.98022 \cdot REL)})$$

where $REL = \frac{DBH}{QMD}$

3) A function of average diameter is calculated {10}

$$GOFAD = 0.21963 \cdot (QMD + 1.0)^{0.73355}$$

4) A growth modifier is calculated using the relative density value and the average diameter value.

$$\text{Modifier} = 1.0\text{-}\exp(-FOFR \cdot GOFAD \cdot \{\frac{310 - BA}{310.0}\}^{\{0.5\}} \quad \{11\}$$

Where: BA = Basal Area per acre

5) Now calculate the predicted diameter growth

$$DG = POTDG \cdot MODIFER \cdot (0.48630 + 0.01258 \cdot \text{Site}) \quad \{12\}$$

Where site = base year 80 Aspen site

Figures 2 through 6 illustrate the behavior of the Aspen Diameter growth function.

DEFAULT VALUES:

SITE INDEX = 40
DIAMETER = 9 in.
CROWN RATIO = 3
BASAL AREA = 110
AVERAGE DIAMETER = 6
RELATIVE DIAMETER = DBH/AD

```
   POT=.47551582-3.8336084E-06*DBH**4.1488229+
+    4.5099964E-02*CR*DBH**.67266425
  IF (POT.LE. 0.0) POT = 0.01

   REL=DBH/AVGDBH
   FOFR=1.0752813*(1-EXP(-1.8902245*REL))
   GOFAD=2.1963083E-01*(AVGDBH+1)**.73354738
   MODVAL=1-EXP(-FOFR*GOFAD*((310-BA)/310)**0.5)
    PREDDGR(I)=POT*MODVAL*(.48630+.01258*SI)
```

Figures 3 through 7 pages 22-26 illustrate the Aspen diameter growth response surfaces.

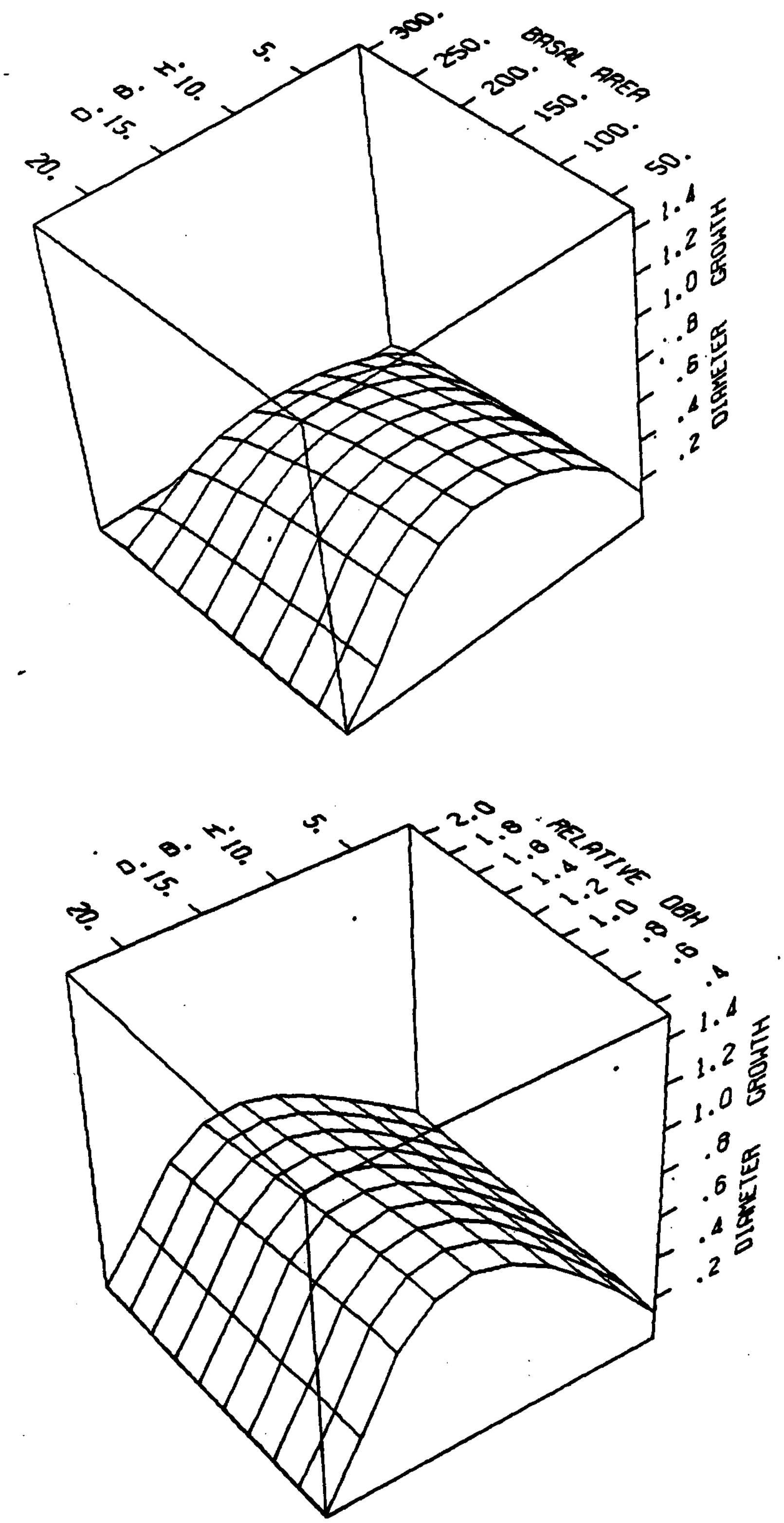

Figure 3. **Aspen diameter growth response surfaces.**

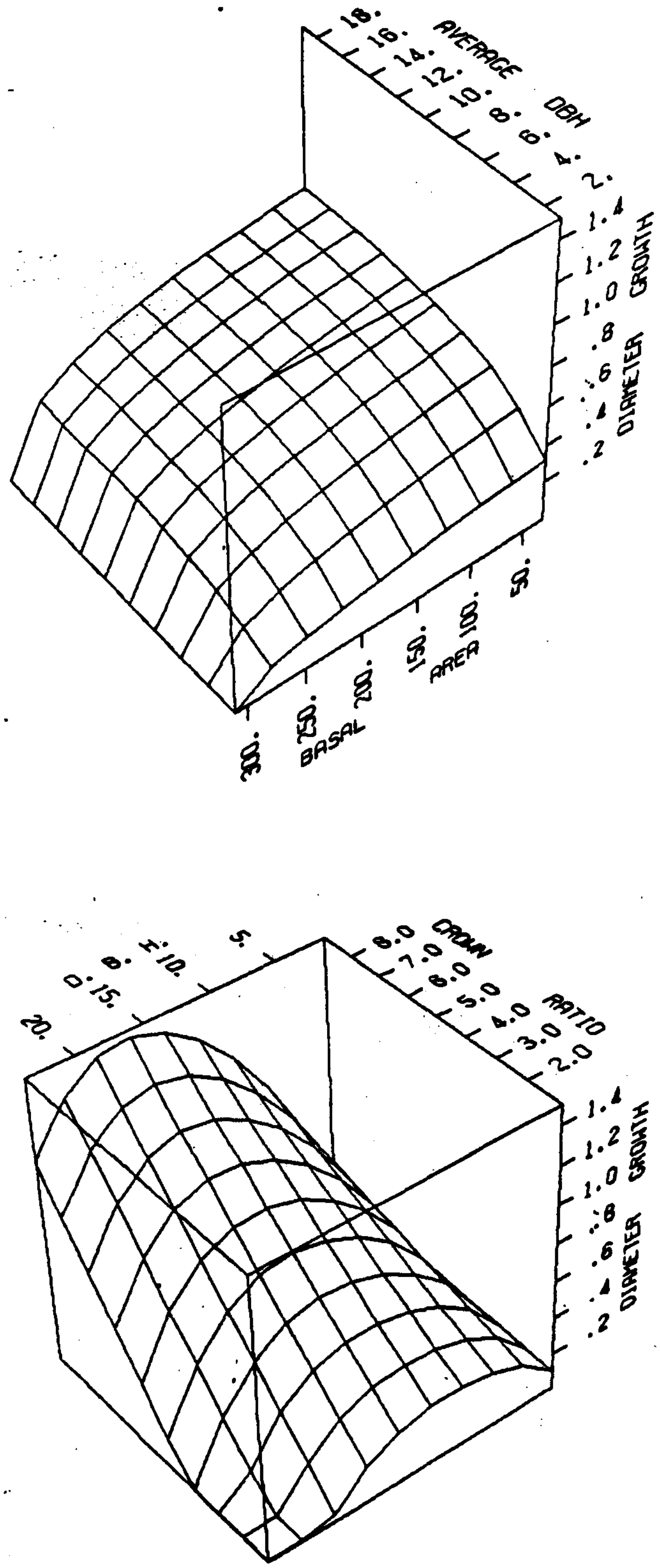

Figure 4. Aspen diameter growth response surface.

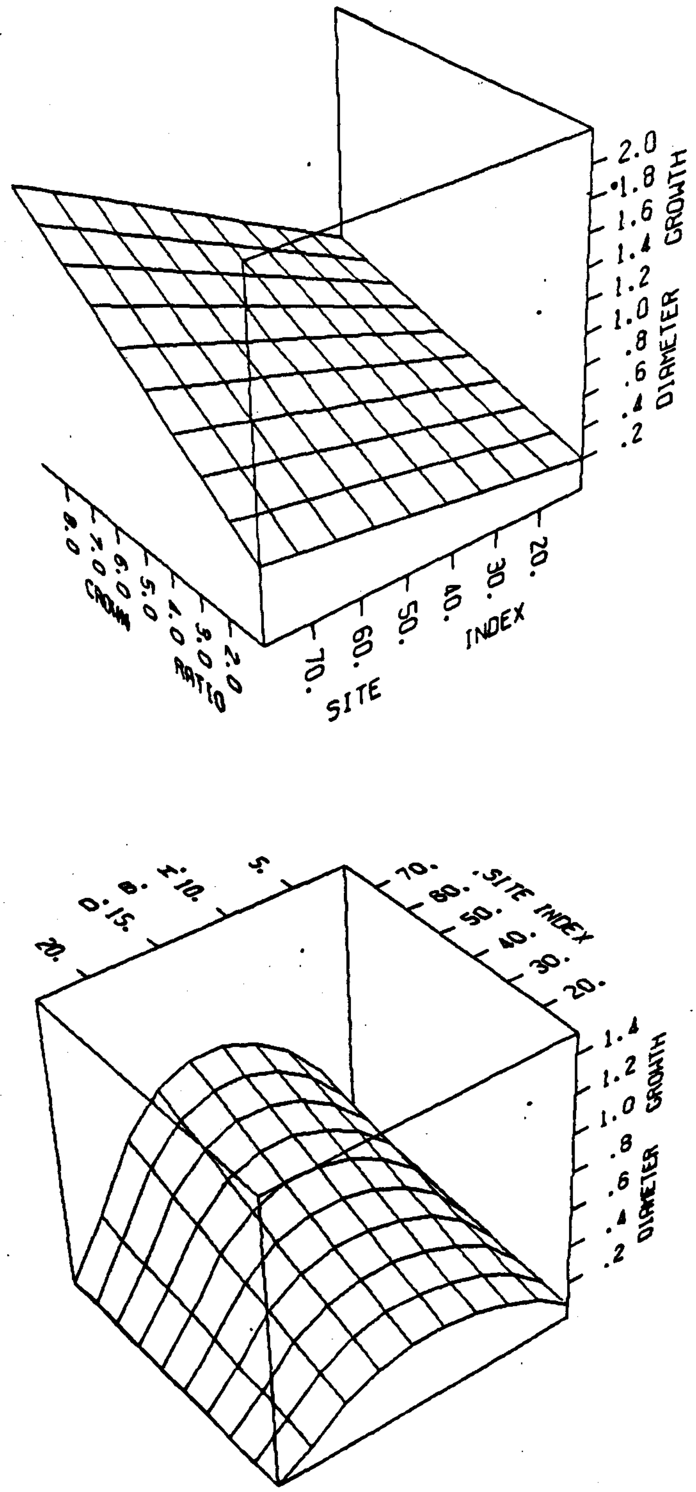

Figure 5. Aspen diameter growth response surfaces.

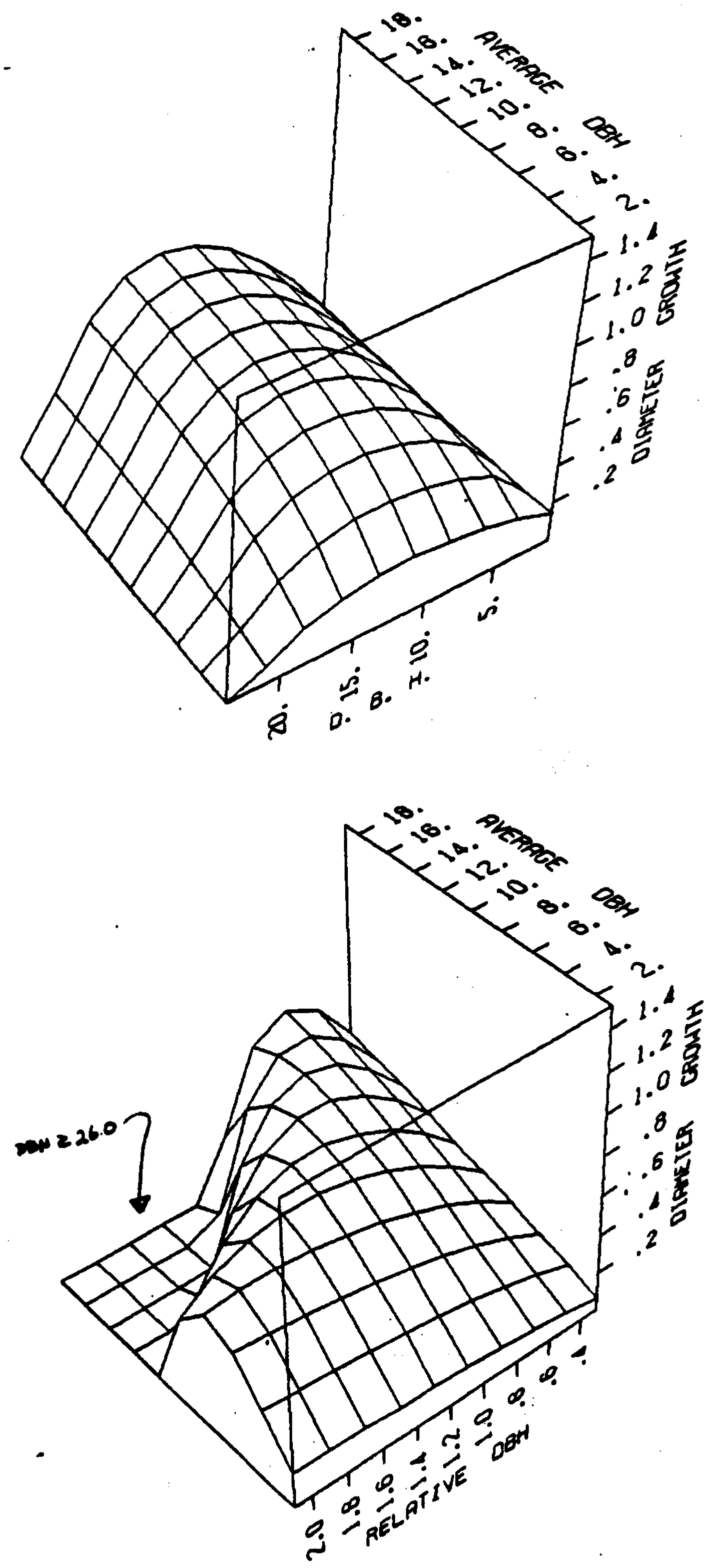

Figure 6. Aspen diameter growth response surfaces.

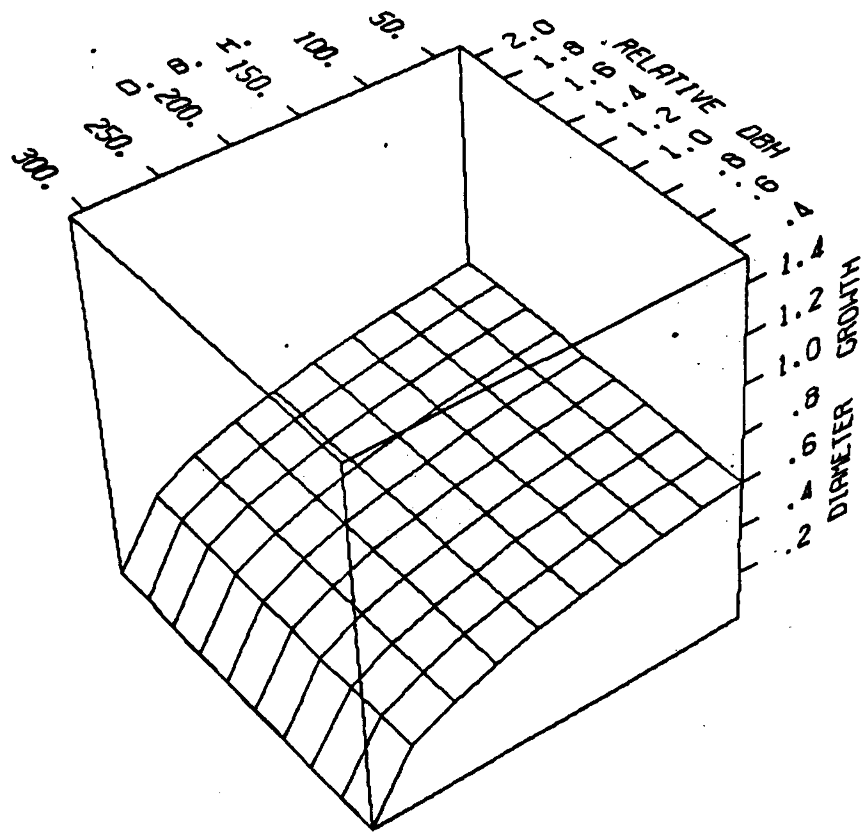

Figure 7. Aspen diameter growth response surfaces.

Large Tree Height Growth (All Species).

Height growth measurements were missing from the data sets used in calibrations of these models. Height growth was calculated by looking up heights at two points in time and subtracting the two height predictions. In this process, the height and diameter are known at the start of the projection period for every tree in the inventory. Diameter growth is predicted for each tree. Height-diameter distributions were fit for each species using Johnson's S_{bb} bivariate distribution (Schreuder and Hafley, 1977). A tree's relative position in the distribution is first determined for the start of projection cycle. The relative position in the distribution is held constant while the diameter is incremented to the end of the cycle. The new height is looked up at the end of the cycle and the height growth calculated by subtracting the two heights. Figure 9 illustrates the principle.

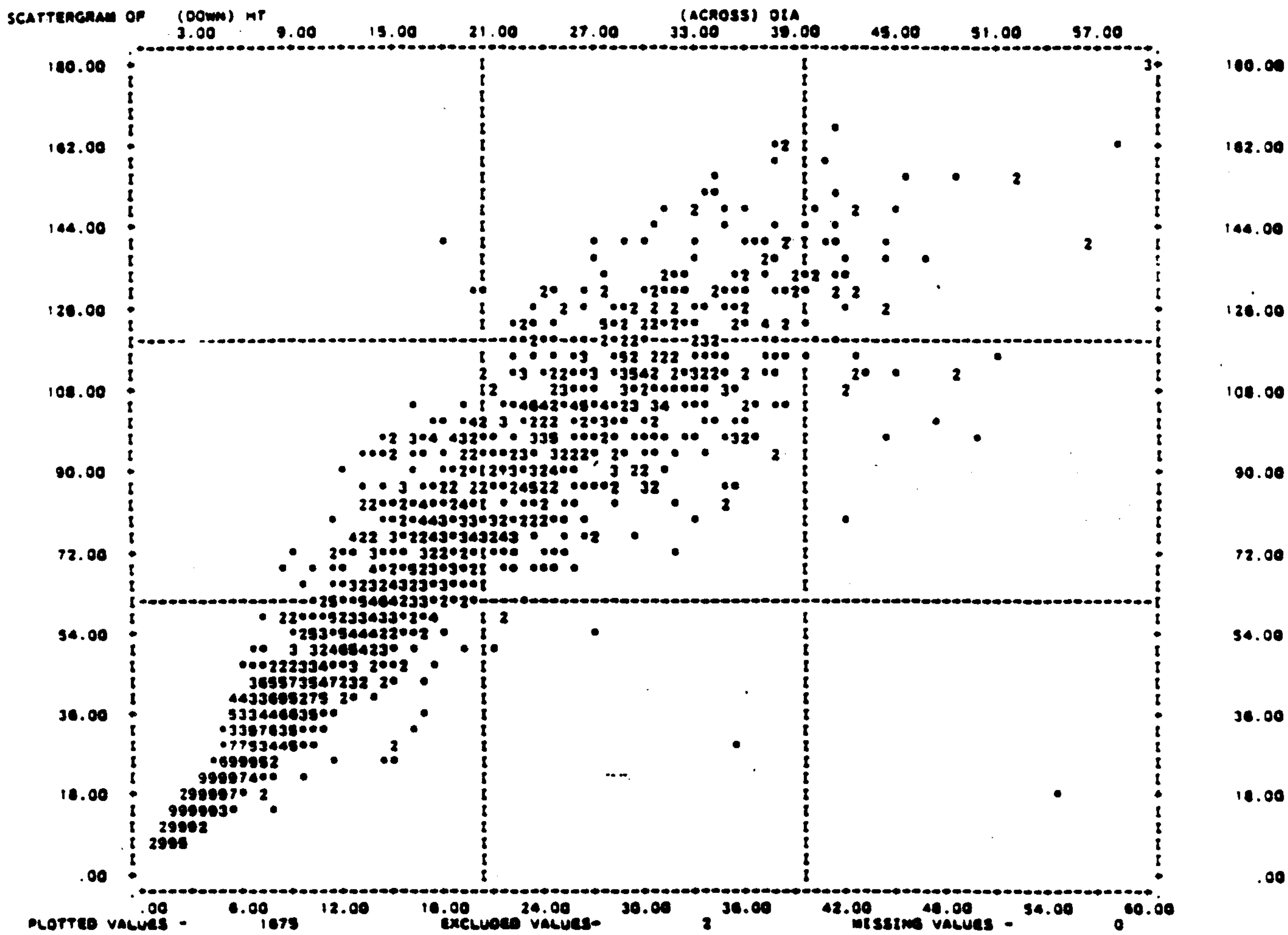

Figure 8. Use of the Johnson's S_{bb} bivariate distribution to obtain height growth. Sample of data for PP crown codes 3-6.

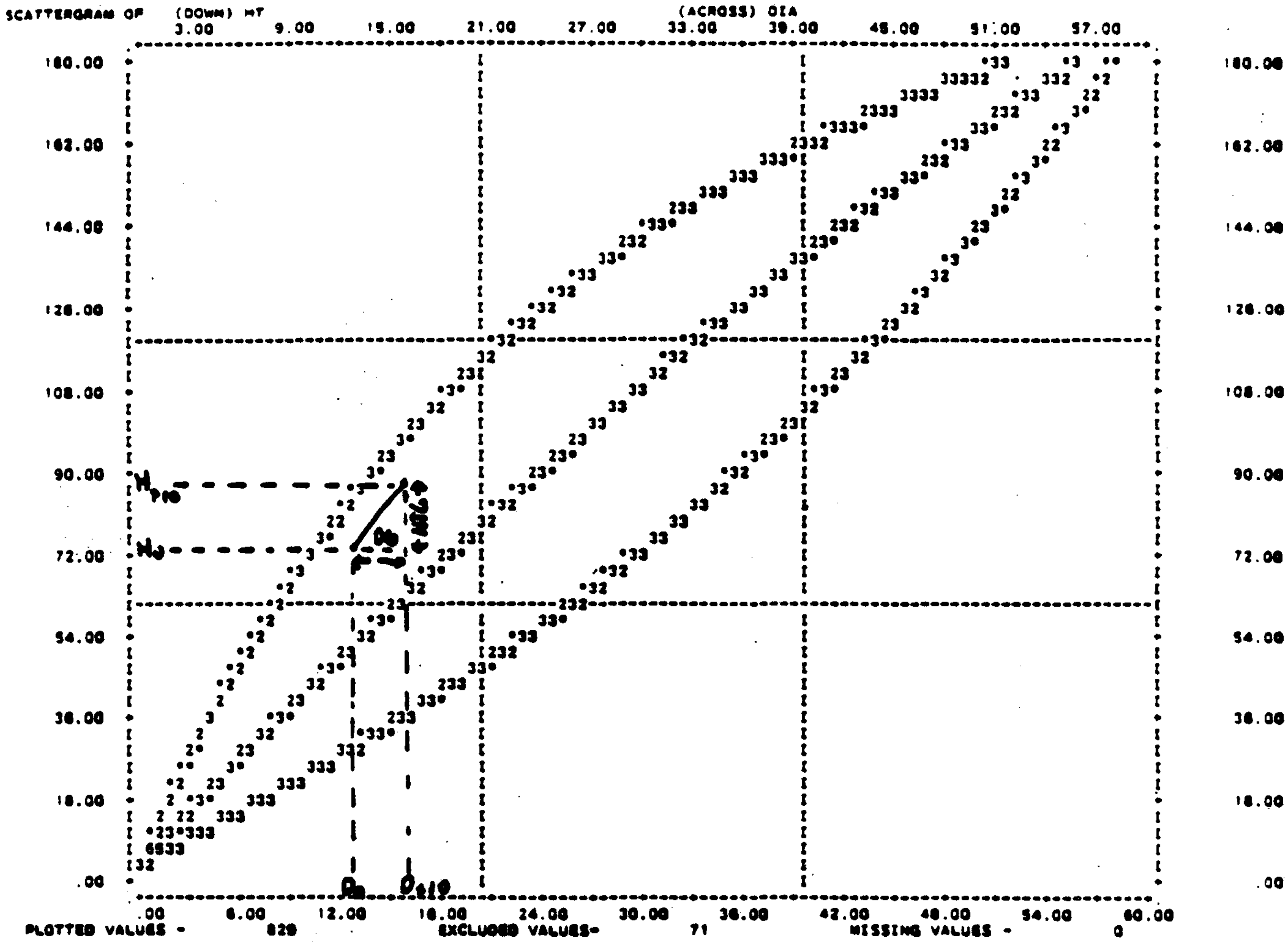

Figure 9. Median and upper and lower 95% S_{bb} confidence band for the data in Figure 4.

Tables 17 and 19 show the coefficients for the S_{bb} distribution in the order shown in Tables 16 and 18.

Height growth calculations follow this sequence:

A. Calculate the relative position of the tree in the distribution.

1. $y_1 = (DBH_0 - XI_1) / b_1$ {13}

   $y_2 = (height_0 - XI_2) / b_2$ {14}

2. $Fby_1 = Ln(y_1 / (1.0 - y_1)$ {15}

   $Fby_2 = Ln(y_2 / (1.0 - y_2)$ {16}

3. $z = (b_4 + b_6 \cdot Fby_2 -$

   $b_7 \cdot (b_3 + b_5 \cdot Fby_1)) \cdot (1.0 - b_7^{\,2})^{-.5}$ {17}

B. Calculate the height 10 years later.

1. $PSI = b_8 \cdot ((DBH_0 + DG/bark - XI_1 /$

   $(XI_1 + b_1 - DBH_0 + DG / Bark))^{b9} \cdot$

   $(exp(z \cdot ((1.0 - b_7^{\,2}))^{.5})/b_6)$ {18}

2. $Height_{+10} = ((PSI / (1.0 + PSI)) \cdot b_2) + XI_2$ {19}

C. Calculate the height growth

   $HTG = H_{+10} - Height_0$ {20}

Variable names are as reported in Schreuder and Hafley.

Table 16. Utah Prognosis Height diameter distribution classes.

Species	Type of Class	Maximum dbh	Maximum Ht	Coefficient Table Index Number
WB	CR 1-2	37.0	85.0	1
WB	CR 3-7	45.0	100.0	2
WB	CR 8-9	45.0	90.0	3
LM	CR 1-2	37.0	85.0	4
LM	CR 3-7	45.0	100.0	5
LM	CR 8-9	45.0	90.0	6
DF	SI <30	50.0	95.0	7
DF	SI 30-40	60.0	110.0	8
DF	SI 40-50	55.0	105.0	9
DF	SI 50-60	50.0	110.0	10
DF	SI 60 +	38.0	110.0	11
AS	CR 1-2	30.0	85.0	12
AS	CR 3-7	30.0	85.0	13
AS	CR 8-9	35.0	85.0	14
LP	CR 1-2	30.0	80.0	15
LP	CR 3-7	35.0	93.0	16
LP	CR 8-9	30.0	80.0	17
ES	SI <30	50.0	105.0	18
ES	SI 30-40	50.0	105.0	19
ES	SI 40-50	60.0	120.0	20
ES	SI 50-60	45.0	120.0	21
ES	SI 60+	45.0	125.0	22
AF	SI <30	35.0	75.0	23
AF	SI 30-40	40.0	95.0	24
AF	SI 40-50	40.0	100.0	25
AF	SI 50-60	40.0	110.0	26
AF	SI 60+	40.0	115.0	27
PP	CR 1-2	55.0	95.0	28
PP	CR 3-7	60.0	115.0	29
PP	CR 8-9	50.0	95.0	30

Table 17. Utah Prognosis coefficients for the height increment model.

Species	Index No.	b Coefficients						
WB	1	1.77836	-.51147	1.88795	1.20654	.57697	3.57635	.90283
WB	2	1.66674	.25626	1.45477	1.11251	.67375	2.17942	.88103
WB	3	1.64770	.30546	1.35015	.94823	.70453	2.46480	1.00316
LM	4	1.77836	-.51147	1.88795	1.20654	.57697	3.57635	.90283
LM	5	1.66674	.25626	1.45477	1.11251	.67357	2.17942	.88103
LM	6	1.64770	.30546	1.35015	.94823	.70453	2.46480	1.00316
DF	7	1.03766	-.10314	1.16073	1.02648	.83396	2.56902	.94303
DF	8	1.63201	.32350	1.30538	1.33112	.81870	2.13984	.80286
DF	9	1.31790	-.36654	1.38496	1.18264	.83039	3.43941	.97246
DF	10	1.00167	-.55765	1.37084	1.29851	.78167	2.80787	.82521
DF	11	.38147	-.67042	1.13209	.92190	.83348	2.92151	1.02351
AS	12	2.00995	.03288	1.81059	1.28612	.72051	3.00551	1.01433
AS	13	2.00995	.03288	1.81059	1.28612	.72051	3.00551	1.01433
AS	14	1.80388	-.07682	1.70032	1.29148	.72343	2.91519	.95244
LP	15	1.85047	-.25580	1.67170	1.53660	.72508	2.82825	.78883
LP	16	1.49353	.08644	1.61150	1.57042	.73267	1.89981	.75184
LP	17	.85472	.14709	1.31510	1.22489	.83830	1.59182	.90003
ES	18	1.84149	.43562	1.50911	1.27174	.83183	2.36779	.98709
ES	19	1.21240	-.15047	1.30622	1.12217	.82399	2.78522	.95913
ES	20	1.42571	-.18256	1.33875	1.10993	.82630	3.40712	.99665
ES	21	1.54101	.20997	1.38766	1.22927	.89085	2.57529	1.00564
ES	22	.40300	-.81957	1.15151	.85881	.80328	3.78573	1.07705
AF	23	2.60522	.33274	1.88966	1.50108	.78085	3.10664	.98298
AF	24	1.95832	.38168	1.53254	1.40855	.77849	2.25099	.84702
AF	25	1.64996	-.03653	1.52713	1.24917	.82371	3.05640	1.00700
AF	26	1.21724	-.03316	1.30125	1.11284	.88781	2.72071	1.03812
AF	27	1.19929	.01214	1.20833	.98180	.89815	2.95870	1.10539
PP	28	1.35731	.03681	1.22927	.98859	.86025	3.13888	1.06969
PP	29	1.01274	.07372	1.30149	1.10133	.83541	2.01632	.98724
PP	30	.53723	-.10060	1.06347	.87482	.86191	1.90485	1.04777

Table 18. Teton Prognosis Height Diameter Distribution Classes.

Species	Crown Classes	Maximum DBH	Maximum Ht	Table Index No.
WB	1-2	37.0	85.0	1
WB	3-7	45.0	100.0	2
WB	8-9	45.0	90.0	3
LM	1-2	37.0	85.0	4
LM	3-7	45.0	100.0	5
LM	8-9	45.0	90.0	6
DF	1-2	60.0	105.0	7
DF	3-7	70.0	120.0	8
DF	8-9	70.0	130.0	9
LP	1-2	30.0	105.0	10
LP	3-7	45.0	110.0	11
LP	8-9	35.0	90.0	12
ES	1-2	50.0	145.0	13
ES	3-7	50.0	145.0	14
ES	8-9	50.0	140.0	15
AF	1-2	20.0	95.0	16
AF	3-7	35.0	110.0	17
AF	8-9	50.0	130.0	18
PP	1-2	37.0	85.0	19
PP	3-7	45.0	100.0	20
PP	8-9	45.0	90.0	21

Table 19. Teton Prognosis coefficients for the height increment model

		SBB Height Model b Coefficients						
Species	Index No.	3	4	5	6	7	8	9
WB	1	1.77836	-.51147	1.88795	1.20654	.57697	3.57635	.90283
WB	2	1.66674	.25626	1.45477	1.11251	.67375	2.17942	.88103
WB	3	1.64770	.30546	1.35015	.94823	.70453	2.46480	1.00316
LM	4	1.77836	-.51147	1.88795	1.20654	.57697	3.57635	.90283
LM	5	1.66674	.25626	1.45477	1.11251	.67375	2.17942	.88103
LM	6	1.64770	.30546	1.35015	.94823	.70453	2.46480	1.00316
DF	7	2.43099	.20403	1.28447	.99886	.79629	5.66171	1.02398
DF	8	1.85710	-.10692	1.40067	1.16053	.78576	3.85554	.94853
DF	9	1.51547	.30923	1.30655	1.23707	.86427	2.24521	.91281
LP	10	2.00207	-.25204	2.04453	1.62734	.72514	2.84910	.91104
LP	11	2.50885	.09740	1.85457	1.48205	.77851	3.49791	.97420
LP	12	1.31478	.21254	1.29774	1.09363	.85692	2.30681	1.01686
ES	13	1.23692	.30499	1.19486	1.09838	.90058	2.08863	.97969
ES	14	1.23692	.30499	1.19486	1.09838	.90058	2.08863	.97969
ES	15	.94647	.31838	1.04318	.95444	.91934	1.78262	1.00481
AF	16	.90779	.33845	1.06402	.81823	.97688	1.95458	1.27034
AF	17	1.36713	.35062	1.25426	1.05571	.90342	2.31128	1.07333
AF	18	1.63172	.60577	1.29877	1.16988	.90860	2.11592	1.00870
PP	19	1.77836	-.51147	1.88795	1.20654	.57697	3.57635	.90283
PP	20	1.66674	.25626	1.45477	1.11251	.67375	2.17942	.88103
PP	21	1.64770	.30546	1.35015	.94823	.70453	2.46480	1.00316

As a test of the SBB logic, a data set of felled trees with measured height growth was plotted. (Figure 10). These were mature trees scheduled for a timber sale. Note that on the whole, the method seems to follow the SBB track. When plantations were processed with the SBB logic it became apparent there was a bias. Usually height growth was underestimated. To correct this bias, a correction is made for young stands. This is done by adjusting the Z value from step A, equation {17}.

$$Z\ adj = .3564 \cdot \text{diameter growth} \cdot \text{cycle length factor} \qquad \{21\}$$

If CCF is less than 100, Z adj is reduced in direct proportion to a trees percentile in the basal area distribution. The adjustment is increased if the tree has a crown of 8 or 9.

Dubbing Missing heights

Usually only a sample is available for heights. If no heights are available the coefficients shown in Table 20 and 21 are used in equation {22}.

$$\text{Height} = \exp\left(A + \frac{B}{(DBH+1.0)}\right. + 4.5 \qquad \{22\}$$

Table 20. Utah Prognosis height dubbing default equations.

	Coefficient	
Species	A	B
DF	4.5879	-8.9277
WF	4.3008	-6.8139
LP	4.3767	-6.1281
ES	4.5293	-7.7725
AF	4.4717	-6.7387
PP	4.6024	-11.4693
AS	4.4421	-6.5405

Table 21. Teton Prognosis height dubbing coefficients.

Species	A	B
WB	4.1920	-5.1651
LM	4.1920	-5.1651
DF	4.5175	-6.5129
LP	4.4625	-5.2223
ES	4.5822	-6.4818
AF	4.3603	-5.2140
Other	4.1920	-5.1651

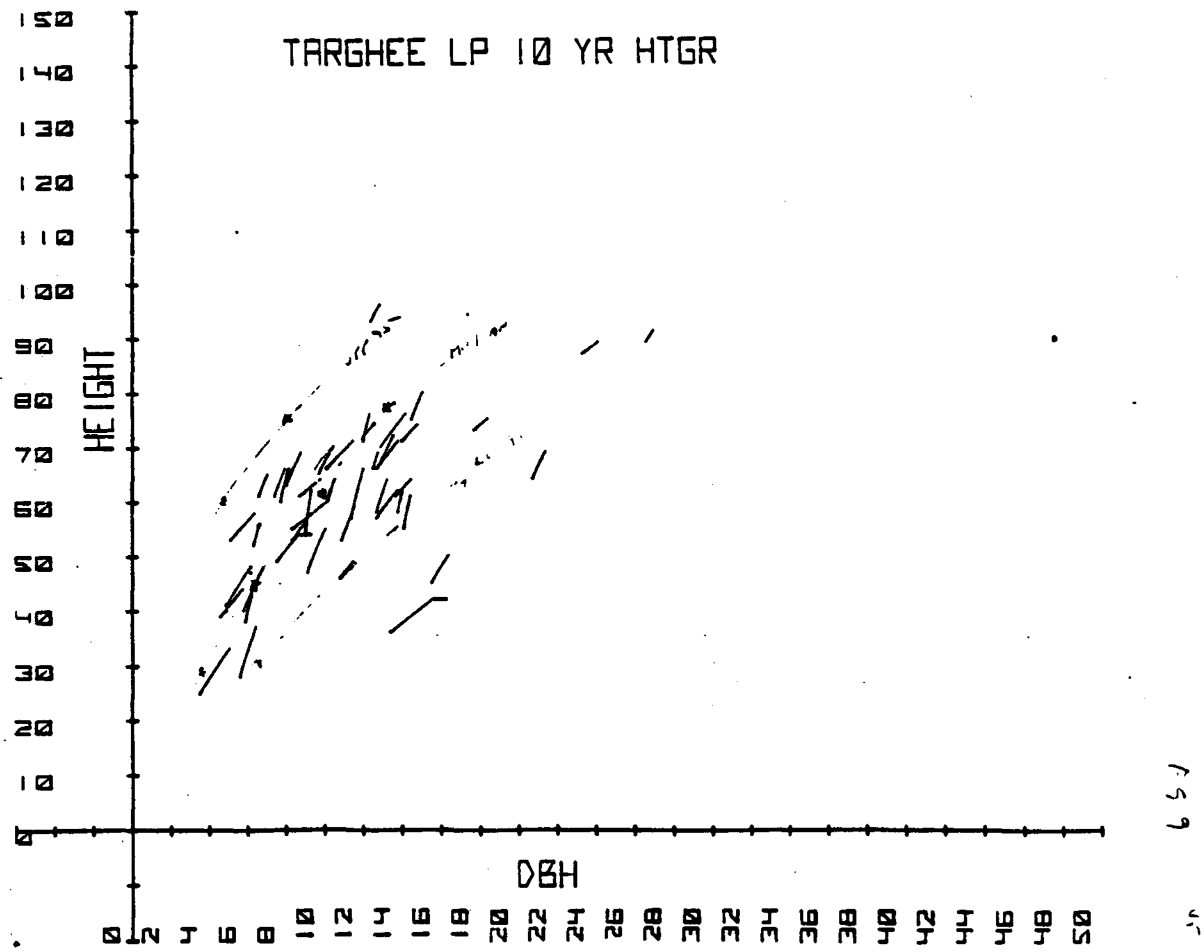

Figure 10. 10-Year Height Growths for felled trees from the Targhee National Forest.

Crown ratio is predicted at the end of each projection cycle using a new technique developed for the south central Oregon/northeastern California (SORNEC) variant. The first step is to estimate the mean stand crown ratio from Stand Density Index [Reineke, 1933]. Next, the Weibull distribution parameters are estimated from the mean stand crown ratio. Individual trees are then assigned a crown ratio from the specified Weibull distribution, either randomly or based on their rank in the diameter distribution. In either case the Weibull distribution is scaled by a density dependent scale factor.

As the growth and yield projection continues through time, the SDI and CCF values change, as does a tree's rank in the diameter distribution. As the SDI values change, so does the Weibull distribution from which crown ratio values are drawn. As the diameter distribution rank changes, a tree's relative percentile in the Weibull distribution changes. As the stand CCF changes, the range of crown ratio values changes.

The change in crown ratio from one projection cycle to the next is obtained by subtracting the crown ratios picked from the appropriate Weibull distributions. This change value is bounded to 10 percent to avoid drastic changes from one cycle to the next.

Equation {23} shows the relationship between number of trees/acre [N], and quadratic mean stand diameter [QMD], used by Reineke. Reineke found the "b" coefficient to be relatively constant at -1.605 for most species. Using this approximation for "b", and transforming to Logarithmic scale gives equation {24}.

$$N = a\ QMD^{b} \qquad \{23\}$$

$$Ln[N] = Ln[a] - 1.605\ Ln[QMD] \qquad \{24\}$$

In earlier trials, plots were constructed for each species in logarithmic scale, showing the relationship between quadratic mean stand diameter and stand density [trees/acre]. A line with -1.605 slope was subjectively drawn on the logarithmic scale plots to form an upper bound, or maximum SDI. This relationship for SORNEC white fir is shown in Figure 11. It is interesting to note how well the -1.605 slope matches the data.

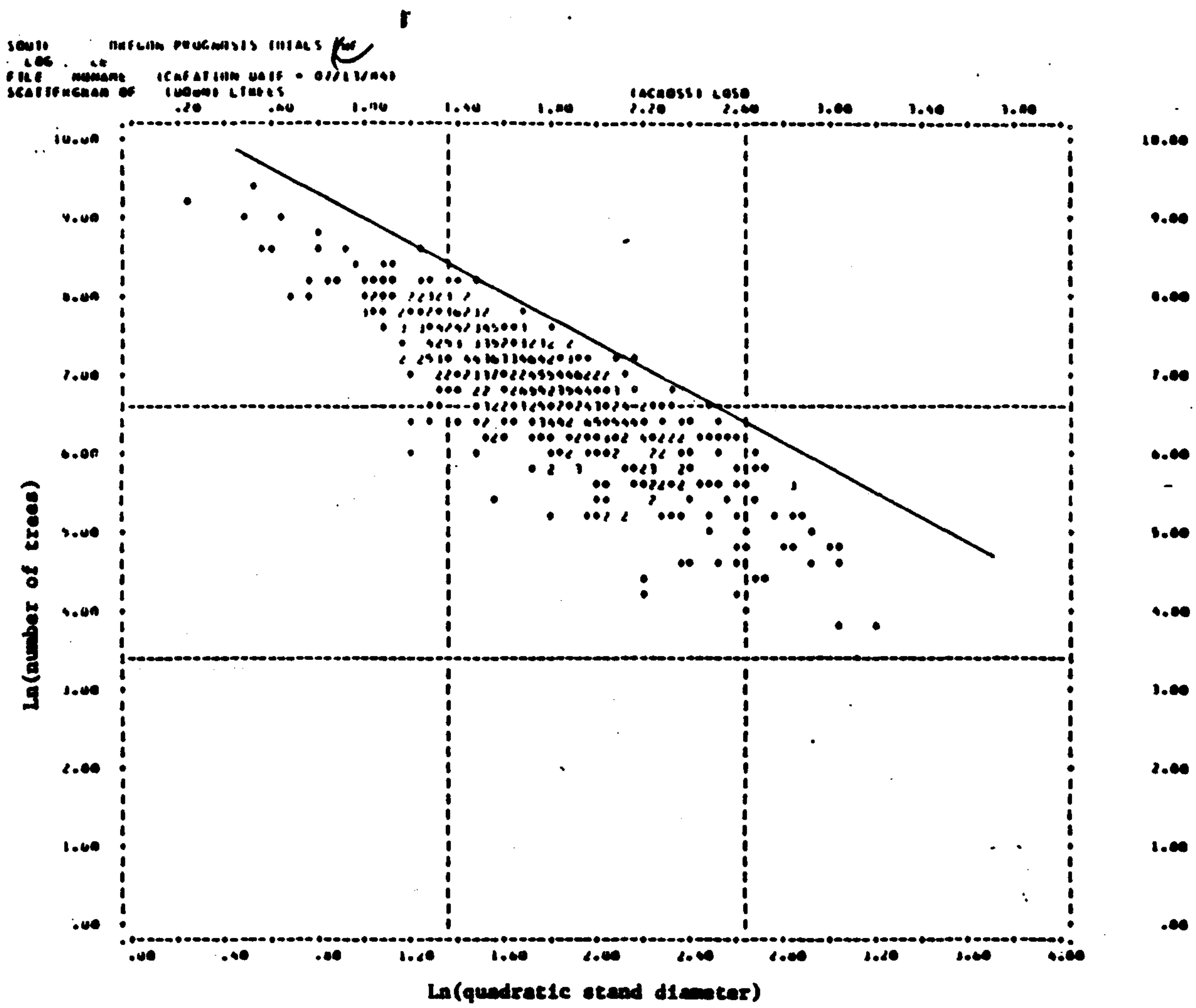

Figure 11. Number of trees versus quadratic stand diameter in logarithmic scale for white fir, south central Oregon/northeastern California.

To estimate the "a" coefficient, a point was picked on either the real scale line or the logarithmic scale line and substituted into equation {23} or {24}, as appropriate. For white fir the point (2.7183,6.25) was used with equation {24}. The maximum SDI value was then calculated by solving the resulting equation for QMD = 10.0

For the Teton and Utah variants, this method was not used. Instead, maximum SDI values were specified by Ron Hamilton in Regional Office, and the equation coefficients were determined accordingly. The maximum value for aspen came from Jim Long (Utah State University). Equation coefficients and corresponding SDI values, by species, are shown in Table 22. In theory, stand density peaks at about 85 percent of maximum (Smith 1984, Long 1984). These 85-percent values are also shown in Table 22.

Table 22. Coefficients and corresponding SDI values, by species, Utah and Teton Prognosis.

J+P - 460
P - 348

Species	"a" (equation 1)	"a" (equation 2)	Max. SDI	85% Level	
WB/LM	33425.5	8.14	830	705	460 similiar to P&J.
DF	23961.7	10.08	595	506	
AS	18122.3	9.80	450	383	
LP	28190.2	10.25	700	595	
ES	26982.0	10.20	670	569	
AF	33425.5	10.42	830	705	
PP	33425.5	10.42	~~830~~	~~705~~	Utah 450
J	33425.5	10.42	~~830~~	~~705~~	Idaho 670 Nevada 670

The Weibull distribution is described by the probability density function shown in equation {25} (Johnson and Kotz, 1970). Parameters were estimated by first constructing a table of tree frequencies by crown ratio code (1 = 0-10%, 2 = 11-20%, etc.) and relative SDI (stand SDI/85% level) for each species. Weibull parameters were then estimated for each relative SDI group with more than 10 observations. Frequency tables and estimated parameters for lodgepole pine are shown in Table 23. Note the decreasing trend in mean crown ratio as relative SDI increases for lodgepole pine.

$$f(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{(c-1)} e^{-\frac{(x-a)^{c}}{b}} \qquad \{25\}$$

Since maximum SDI values were not available for all nine of these species, the SDI value for juniper was used for whitebark pine and limber pine. The "a" (location) coefficient was found to be nearly constant across relative SDI groups for a given species. Consequently, it was set to a constant and the remaining parameters recomputed. The "b" (scale) parameter showed a high correlation with the mean crown ratio, while the "c" (shape) coefficient showed no consistent relationship to mean crown ratio. These parameters are also shown in Table 23.

Table 23. Number of trees by crown ratio code and relative SDI for Lodgepole pine and the corresponding Weibull parameters.

	Crown Ratio Code										Mean Crown	Weibull Parameters		
Rel. SDI	1	2	3	4	5	6	7	8	9	Total	Ratio	a	b	c
0-10	0	0	0	3	1	4	5	4	0	17	6.35	0	6.89	5.76
11-20	1	3	11	11	21	14	14	10	2	87	5.39	0	6.01	3.40
21-30	4	15	44	60	71	37	46	25	12	314	5.14	0	5.75	3.06
31-40	15	47	101	115	84	52	41	31	8	494	4.48	0	5.04	2.62
41-50	4	41	135	132	106	36	29	10	4	497	4.19	0	4.69	3.00
51-60	12	48	177	159	71	37	12	0	2	518	3.77	0	4.21	3.14
61-70	8	33	89	83	31	13	1	0	0	258	3.54	0	3.94	3.40
71-80	0	14	30	16	7	2	1	0	0	70	3.37	0	3.76	3.22
81-90	0	2	8	2	3	1	0	0	0	16	3.56	0	3.97	3.40

Using mean stand crown ratio (MCR) values and midpoints of the relative SDI classes (RSDI) from frequency tables such as those shown in Table 23, least squares regression equations were developed to predict MCR from RSDI. The simple linear model MCR = d0 + d1 · RSDI was used, and data from all nine species were available for this regression. Regression results are listed in Table 24.

Table 24. Regression results for the relationship MCR = d0 + d1 · RSDI, by species, for Utah and Teton Prognosis.

Species	d0	d1
White bark/Limber	6.199	-0.022
Douglas-Fir	7.463	-0.029
White Fir	7.658	-0.035
Aspen	4.017	-0.015
Lodgepole Pine	6.006	-0.0352
Englemann Spruce	6.811	-0.010
Subalpine Fir	7.658	-0.035
Ponderosa Pine	6.199	-0.022

As stated previously, the Weibull "a" parameter was considered constant for a given species. Equations predicting the Weibull "b" parameter from mean crown ratio were developed through ordinary least squares regression. Since no clear pattern emerged for the Weibull "c" parameter, it too was considered a constant, and estimated as the arithmetic average of "c" values across relative SDI groups for a species. The estimated parameters for the various species are shown in Table 25.

Table 25. Weibull parameters for modeling crown ratio in the Utah and Teton Prognosis.

Species	Weibull Parameters a	b	c
WB/LM	1.0	-0.82631 +1.066 ·MCR	3.31
DF	1.0	-0.24217 +0.965 ·MCR	-7.95
WF	1.0	-0.89553 +1.077 ·MCR	1.74
AS	0.0	-0.08414 +1.148 ·MCR	2.78
LP	0.0	0.17162 +1.073 ·MCR	3.15
ES	1.0	-0.90648 +1.081 ·MCR	3.49
AF	1.0	-0.89553 +1.077 ·MCR	1.75
PP	1.0	-0.82631 +1.062 ·MCR	1.03

Once the Weibull distribution is specified, crown ratios are assigned to individual trees. In the Utah and Teton Prognosis, crown ratios are assigned based on the tree's relative position in the Weibull distribution. This relative position is determined in one of two ways. If a diameter is not specified, the tree is assigned a relative position randomly. If a diameter is specified, the tree's relative position is based on the tree's rank in the diameter distribution, and is calculated as its diameter distribution rank divided by the total number of trees. The lower truncation point for choosing crowns from the Weibull distribution is the .05 percentile point. The upper limit is the .95 percentile point, unless a density dependent scale factor is invoked.

The density determined scale factor (SCALE) is a function of the stand's crown competition factor (RELDEN). The function given in equation {26} was determined by examining plot data and comparing the stand CCF with associated tree crown ratios. It was determined that densities indicated by a CCF less than 100 had little or no effect on crown ratios, while trees in high density stands with a CCF of 400 or more could expect a 50-percent crown reduction.

$$\{26\} \quad \begin{aligned} &SCALE = 1.0 && \text{for } 0 \le CCF < 100 \\ &SCALE = (1.0 - .00167\,(RELDEN - 100.0) && \text{for } 100 \le CCF < 400 \\ &SCALE = 0.5 && \text{for } 400 \le CCF \end{aligned}$$

Mortality

The mortality routine used in the Teton and Utah variants is patterned after the SORNEC variant, and is different from other Prognosis mortality routines in two ways. First, the number of trees dying is determined by stand density index rather than the approach toward normality or basal area maximum schemes used in other variants. Second, the user can alter the distribution of mortality across diameter classes, rather than have an equal proportion of each class dying, as in other variants. These differences result in a mortality routine which is very responsive to changing stand conditions, and very flexible so users can tailor mortality to match local conditions.

The logic determining the number of mortality trees each cycle is shown in Figure 12. In most cases, once a stand reaches the .85 level curve it tracks down that curve for the remainder of the projection.

If the number of trees is initially above 90 percent of the level, the maximum line is raised to correspond to that number of trees, a message is printed, and processing continues.

If a stand is initially between the .85 level and the .90 level, the number of trees drops to the .85 level the first cycle. If a stand begins between the .55 (.60 for pp) and .85 level curves, it tracks down a linear curve until it reaches the .85 level curve. If a stand comes into Prognosis below the .55 (.60) level curve, due to some built-in background mortality, then follows a linear curve to the .85 curve.

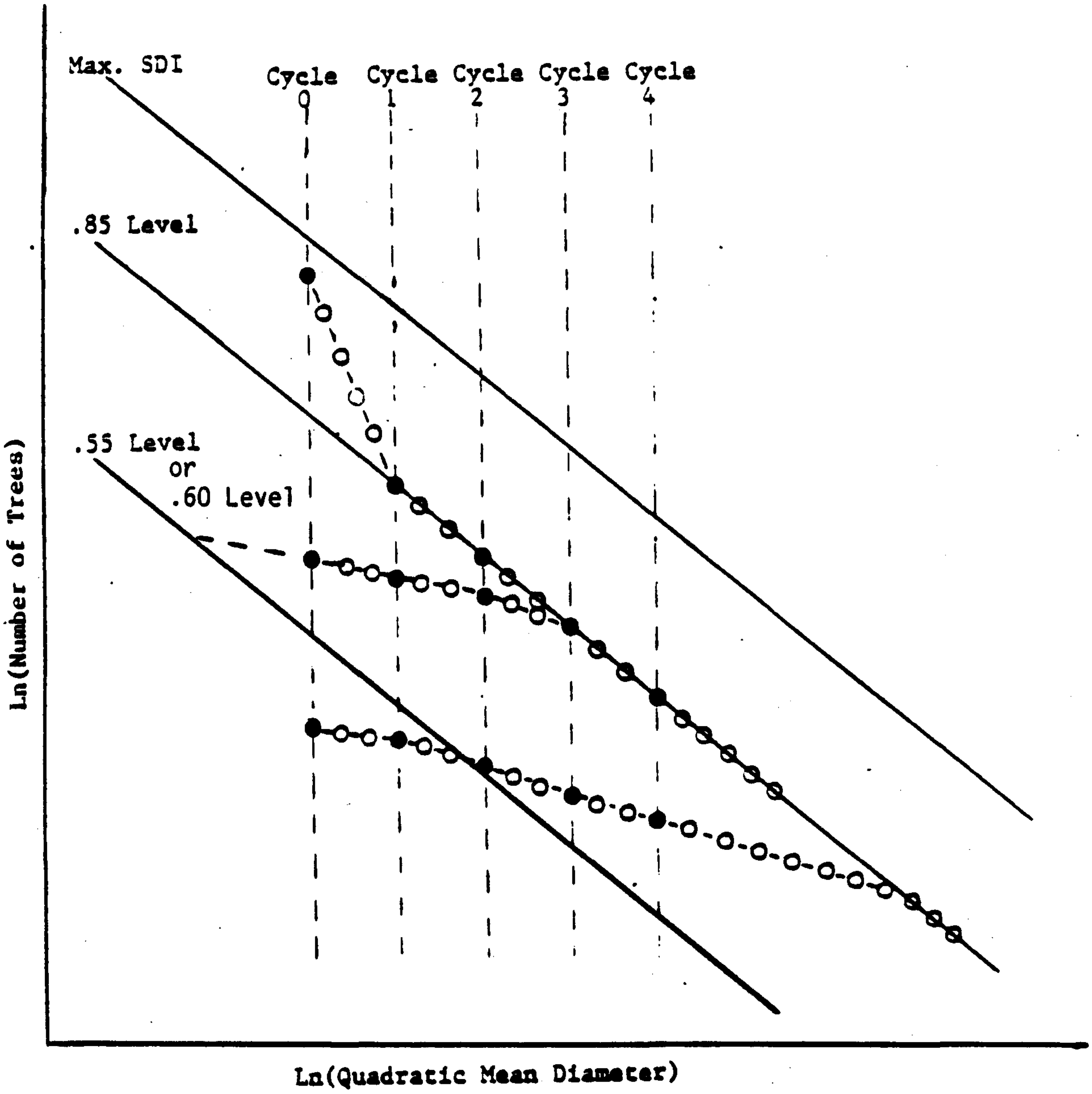

Figure 12. Logic for determining the number of mortality trees each cycle in the Teton and Utah Prognosis variants.

The linear curve between the .55 (.60) and .85 level curves is dependent on the squared Quadratic Mean stand Diameter (QMD). Stands with a small QMD will approach the .85 level curve faster than a stand with a larger QMD. Noticeable jumps in mortality occur when a stand passes the .55 (.60) level, and again when it reaches the .85 level. This is another advantage over other variants since it helps to identify management objectives.

Species specific maximum SDI values embedded in the Teton and Utah variants are shown in Table 22. In mixed species stands, the SDI value is based on the species representing the most basal area. Maximum SDI values can be changed using field 5 on the BAMAX keyword.

Once the number of mortality trees has been determined, the Prognosis "PROB" values (that is, the number of trees a tree record represents) are adjusted. Traditionally, mortality is distributed equally across diameter classes; in other words, the PROB value for every tree record is decreased slightly. This is the default condition in the Teton and Utah Prognosis variants, however, other options are available. These other options are invoked using fields 6 and 7 of the BAMAX keyword, and field 6 of the MORTMULT keyword.

If a numeric code 1 is placed in field 6 of the BAMAX keyword, mortality will be from below by diameter. The tree records are arranged in ascending order by diameter, the PROB values are adjusted beginning with the first record and continuing through the list until the specified number of mortality trees has been reached.

If a numeric code 2 is placed in field 6, tree records are arranged in descending order and mortality is from above by diameter. In this case, however, PROB values are adjusted until specified basal area has been removed, as opposed to a specified number of trees.

If a code 3 is specified, tree records will be arranged in ascending order by species specific relative growth rates, and the poorest growing trees will be killed first. The relative growth rate is defined as the trees' actual basal area growth, divided by a species specific maximum basal area growth, which is derived from equations embedded in the program.

Field 7 of the BAMAX keyword is used to specify a flip diameter for changing between code 1 type mortality and code 2 type mortality. In other words, when a code 1 type mortality is specified in field 6, the program will automatically switch to code 2 type mortality when the stand quadratic mean diameter exceeds the specified flip diameter. The default flip diameter is 6.0 inches. If you do not want this flip to occur (i.e., you want mortality from below throughout the projection), specify a high flip diameter, such as 999.0, in field 7 of the BAMAX keyword. If the flip occurs and the stand quadratic mean diameter then falls back below the specified flip diameter because of big trees being removed, the program automatically flips back to code 1 type mortality. However, if you specify code 2 type mortality, you only get mortality from above; the automatic flipping does not take place.

Field 6 of the MORTMULT keyword is used to specify the mortality efficiency by species. This is used in conjunction with mortality codes 1-3 (specified in field 6 of BAMAX keyword) to indicate the proportion of trees represented by the tree record which will be attributed towards mortality. The default value embedded in the program is .90. In other words, as the program processes through the tree records, it will take 90 percent of the trees represented by the first tree record (by diameter, basal area, or basal area growth), 90 percent of the trees represented by the second tree record, and so on, until it has reached the specified mortality. Decreasing the mortality efficiency value will spread the mortality across more tree records.

It is important to note that field 1 of the MORTMULT keyword is the date/cycle that the specified change goes into effect. Consequently, you could possibly change the mortality efficiency every cycle by species, if desired. This ability, in conjunction with the codes specified on the BAMAX keywords, allows the user to design many combinations of mortality distributions.